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Underwater Methods for Study of Salmonids in the Intermountain West

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RESEARCH SUMMARY

Underwater observation using snorkeling gear is an accepted technique for censusing fish populations in flowing waters. Several factors, including the behavior of the target fish species and attributes of the physical habitat, can bias underwater counts. This paper describes the use of underwater observation and outlines procedures for estimating fish abundance, the size structure of populations, and habitat use. It also provides criteria for identifying fish underwater.

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INTRODUCTION

Underwater observation with snorkeling gear is a valuable tool for studying fish populations and assessing how fish use habitat in flowing waters. Precise estimates of fish abundance can be obtained using underwater counts (Griffith 1981; Northcote and Wilkie 1963; Schill and Griffith 1984; Zubik and Fraley 1988). However, several factors, including the behavior of the target fish species and attributes of the physical habitat (stream size, water clarity, temperature, and cover), can bias results.

This guide was developed to assist biologists in identifying and accounting for potential biases and to encourage a standardized procedure for the use of underwater techniques to survey salmonids in streams. The guide addresses the principal resident and anadromous salmonids found in the Intermountain West (Idaho, Montana, Nevada, Utah, and western Wyoming).

CONSIDERATIONS BEFORE THE SURVEY

Before using underwater techniques several factors need to be considered, including study objectives, safety, equipment, training, and ethics.

Objectives

Biologists should carefully consider the objectives of the study before deciding whether underwater observation is the appropriate sampling technique. Underwater observation can provide quantitative information on the abundance (Schill and Griffith 1984), distribution (Hankin and Reeves 1988), size structure (Griffith 1981), and habitat use (Fausch and White 1981) of salmonids. Underwater techniques may also be useful for capturing salmonids in small streams (Bonneau and others, in preparation). Biases can result, however, unless certain conditions of depth, water clarity, and temperature are met (see Recommended Snorkeling Protocols, Minimum Criteria).

If minimum criteria are met, underwater observation has advantages for sampling fish populations. Snorkeling is feasible where environmental conditions such as deep, clear water of low conductivity may limit the effectiveness of electrofishing (Schill and Griffith 1984). Because of the small amount of equipment required for snorkeling, the technique can be used in remote locations where it may be difficult to use other sampling apparatus such as traps, nets, and electrofishing gear. Snorkeling is especially applicable for censusing fish populations in roadless areas (Thurow 1985). Because fish are not handled and disturbance is minimized, snorkeling is useful for sampling stocks of fish that are protected or rare. Less time is required to complete snorkel surveys, and the technique is more cost effective than mark-recapture or removal methods typically used to estimate abundance (Hankin and Reeves 1988; Schill and Griffith 1984).

Snorkeling is a relatively unbiased method for observing fish in their natural environments (Heggenes and others 1990). Snorkelers can observe spawning, feeding, movements, and other behaviors without disturbing the fish (Helfman 1983). Snorkelers can also measure environmental variables such as temperature, velocity, and depth in precise locations.

Underwater observation also has disadvantages. Fish are not handled, so snorkelers must estimate fish size (Grunder and Corsi 1988). Snorkelers may fail to detect fish, count fish more than once, incorrectly estimate fish size, and misidentify fish (Griffith and others 1984). Counting fish accurately in a dense population is difficult (Heggenes and others 1990). Some species and sizes of fish are more easily seen than others (Hillman and others 1992). Small fish and species that remain near the substrate may be more difficult to see than larger, more mobile species (Helfman 1983). Differences in fish behavior during different times of the day or year also may bias observations (Rodgers and others 1992). Instream cover can limit the accuracy of underwater counts if fish are concealed. Counts completed in habitat lacking cover may be more accurate than those completed in complex habitat with abundant cover (Rodgers and others 1992).

Safety

Although underwater observation avoids the hazards of electrofishing, safety should be emphasized (Griffith and others 1984). Snorkelers should always have a partner, either on shore or in the water. Never attach ropes or survey tapes to a snorkeler. Assess the hazards of the site before entering the water. Avoid areas of extreme water velocity and turbulence, especially those immediately upstream from debris jams or bedrock outcrops. If it becomes necessary to survey turbulent stream reaches, attempt to complete surveys from the channel margins and avoid entering the most turbulent locations. Use extreme caution when snorkeling under and within debris jams to avoid entrapment. Stay alert for rattlesnakes, since they often live in riparian zones. Recognize the symptoms of hypothermia and know how to treat it. Exercise extreme caution when conducting surveys at night and during the winter when snorkelers may be exposed to additional hazards. Require all crew members to complete cardiopulmonary resuscitation (CPR) and first aid training. Carry a first aid kit that includes a cardiopulmonary resuscitation mask and a device for extracting poison.

Equipment

Daytime snorkeling in water warmer than 8 °C requires only a minimum of equipment: full neoprene wetsuit (6.4 mm thick), hood, gloves, mask, snorkel, and data recorders. Suits should be of black or dark blue, rather than of bright colors that may startle fish. In turbulent streams, knee and elbow pads provide added protection. Pads can be ordered on the suit, purchased separately, or cut from surplus suits and glued on. Masks may be worn directly over contact lenses, or prescription masks can be purchased for snorkelers who wear glasses. Masks with front and side lenses increase the observer's field of view. It is advisable to carry an extra mask and snorkel for each team on backcountry trips. Neoprene socks worn inside canvas tennis shoes or wading shoes are more durable than neoprene booties and protect the feet better. Fins are useful in large rivers where counts must be conducted while floating downstream. A can of black neoprene wetsuit cement should be carried for patching holes; the cement dries in 10 minutes, forming a durable bond. Wetsuit zippers should be well lubricated with wax or graphite.

Data can be recorded on a slate or cuff carried by the snorkeler. I prefer a cuff cut from a piece of PVC plastic pipe 10 cm in diameter and 20 cm long, modified from the design described by Helfman (1983). The pipe is cut in half, producing two halves each 20 cm long. Four holes are drilled at the corners of each cuff, and a loop of surgical tubing is threaded through each pair of holes. The cuff slides over the snorkeler's arm and is secured by tightening the surgical tubing. Pencils may be stored inside the lengths of surgical tubing. The cuff fits comfortably on the snorkeler's forearm; both hands remain free. Hand tally counters are useful if large concentrations of fish of several sizes or species are encountered.

Underwater observation in cold water or at night may require specialized equipment. If water temperatures are consistently below 8 °C, a drysuit should be worn. It allows snorkelers to complete counts comfortably, even in water near 0 °C. Two types of drysuits are widely available, neoprene and nylon. Both types are durable, but the nylon suit is more lightweight and compact. Various layers of undergarments can be worn inside, enabling a snorkeler to work comfortably in a broad range of water temperatures. Unless the suit will be used for scuba diving, it should be purchased without valves and with attached latex socks. Layers of wool or pile should be worn inside and over the latex socks. Knee and elbow pads protect the snorkeler and the suit.

Several excellent hand-held halogen lights are available for night snorkeling. When a beam of light is focused on fish, they typically maintain their position for 2 to 3 seconds before swimming away. Most species will hold their position longer if underwater lights with red filters are used (Hillman 1993). A filter can be made from red Plexiglass. No other specialized equipment is needed for night snorkeling.

Training

Although snorkeling is easy to learn, training and practice are required to correctly identify species of fish underwater, estimate fish sizes accurately, and complete precise counts. All snorkelers, whether novice or experienced, will improve their abilities with annual training. Snorkelers should review available literature describing snorkeling techniques before beginning practice sessions (see References). Experienced snorkelers should conduct training sessions, administer tests, and review the results with individual snorkelers. The objectives of the study should be clearly stated at the start of the training.

Training should be structured to address equipment, safety, ethics, techniques, and data collection. Select locations for training where snorkelers can practice the selected technique under field conditions simulating those of actual surveys. Have snorkelers practice identifying, counting, and estimating the size of target species.

Identifying Species—Snorkelers may familiarize themselves with the species to be surveyed by reviewing drawings, color plates, and photos; viewing videotapes; visiting aquaria; and snorkeling with experienced

snorkelers. See Sigler and Miller (1963), Scott and Crossman (1973), Simpson and Wallace (1978), or Behnke (1992) for detailed species descriptions, drawings, and color plates. Carl and others (1959) and McConnell and Snyder (1972) presented keys and illustrations to identify juvenile resident and anadromous salmonids. Martinez (1984) provided detailed comparative descriptions of trout larvae. The species included in this guide (see Species Identification and Habitats) represent the principal salmonids in the Intermountain West. If available, underwater videotapes are excellent tools to assist snorkelers in identifying species under field conditions. Aquaria, or other fish facilities with observation windows, offer an opportunity to observe salmonids underwater.

There are several ways to test snorkelers' abilities to identify species underwater. One method is to capture several species of fish and place them in temporary live cages. Snorkelers independently view each fish and report their results to an instructor. Or, an instructor in the water points out fish for a snorkeler to identify and record. In both cases, results are reviewed with the snorkeler; training continues until all snorkelers identify target species accurately. The stream reach to be surveyed on a given sampling trip offers the best location to practice species identification. Snorkelers should practice throughout the field season.

Estimating Fish Size—Accurately estimating the size of fish underwater requires practice. Objects viewed underwater are magnified about 1.3 times. One way to estimate a fish's size is to approach it underwater, align its snout and tail with adjacent objects, and measure that distance with a ruler (Cunjak and Power 1986). Snorkelers can carry a ruler, mark one on their counting sleeve, or use a known distance (index finger to thumb, for example). Swenson and others (1988) described a method for estimating fish size underwater by using a dive mask with a calibrated bar attached to it.

Snorkelers can practice estimating fish sizes by viewing objects and fish of known sizes underwater. Calibrated wooden dowels or floating cutouts of fish of various sizes can be attached to weights and distributed throughout a stream channel. Snorkelers approach each object and estimate its size. Live fish of known size can also be used. One method is to individually mark fish of known sizes in a stream reach. Snorkelers approach each marked fish and estimate its size. Another method is to capture fish of several size classes and place them in temporary live cages (Rich 1993). Snorkelers independently view each fish and report their results to an instructor.

Training improves snorkelers' abilities to estimate fish sizes accurately. Griffith (1981) reported that five observers were tested on their ability to estimate lengths of 15 fish underwater. Before training, from 52 to 72 percent of the estimates were within 25 mm of the true length. After 1 hour of practice, the most experienced observers estimated fish size within 25 mm of the true length in 90 percent of the trials. Rich (1993) trained snorkelers with no previous experience, using live cages in a hatchery raceway. After 1 day of training, the novice group was able to estimate fish size within 25 mm of the true length in more than 90 percent of the tests. Snorkelers should continually check their size estimates throughout the field season.

Estimating Fish Abundance—Snorkelers should be familiar with the size of sampling units they will survey and the method they will use to estimate fish abundance. The selection of sampling units depends on the objectives of the study and the physical characteristics of the stream (see Selecting Appropriate Sampling Units). Select a stream reach with physical characteristics similar to those that crews will actually survey, and train snorkelers to duplicate the proposed snorkeling method. For example, if the survey will be in small streams and a lone snorkeler will proceed upstream while counting all fish in individual habitat units, duplicate those conditions in training. Provide snorkelers with an opportunity to count the total number of target salmonids, recording them by species and size class in several sampling units. Test snorkelers' ability to make precise counts of fish by comparing the counts of several observers in a stream reach. If feasible, establish sampling units that contain a known number of fish of known sizes for testing snorkelers' abilities to complete precise and accurate counts.

Ethics

Biologists have an incomplete understanding of the distribution and abundance of many native salmonids. Snorkelers surveying streams in the Intermountain area may encounter several protected native fish species that warrant special consideration. Snake River spring/summer and fall chinook salmon (*Oncorhynchus tshawytscha*) are protected as threatened species and sockeye salmon (*O. nerka*) are protected as an endangered species under Section 7 of the Endangered Species Act. At the request of the National Marine Fisheries Service, the Forest Service and other agencies are establishing protocols to minimize any potential effects snorkel counts may have on these species. Snorkelers and survey crews should avoid areas where adult salmon spawn.

Lahontan cutthroat (*O. clarki henshawi*) and Paiute cutthroat trout (*O.c. seleniris*) are federally protected as threatened species. Bull trout (*Salvelinus confluentus*), Bonneville cutthroat (*O.c. utah*), Colorado river

cutthroat (*O.c. pleuriticus*), finespotted cutthroat (undescribed), redband trout (*O. mykiss* ssp.), and Montana grayling (*Thymallus arcticus montanus*) are listed as Category 2 candidates under the Endangered Species Act and are undergoing a status review. Westslope cutthroat (*O.c. lewisi*) and Yellowstone cutthroat trout (*O.c. bouvieri*) are listed as sensitive species by the Forest Service, U.S. Department of Agriculture, and the States of Idaho and Montana. Steelhead (*O. mykiss*) are listed as a sensitive species by the Forest Service and the State of Idaho. Some States have legislation making it illegal to harass any fish. Under Title 36 Idaho Code, it is illegal to "harass any fish by striking it...or chasing it up or downstream in any manner." Crew members should not touch or in any way disturb protected fish while conducting snorkel surveys. If the study objectives require capturing federally protected species, a National Marine Fisheries Service or U.S. Fish and Wildlife Service permit will be required in addition to a State collecting permit.

Fish population surveys provide information that is used to sustain and enhance fisheries resources. Snorkelers may encounter concentrations of fish and large individuals of some species. These fish may be highly vulnerable to angling. Considering the sensitive status of many native fish in the Intermountain West, crew members should not harvest fish from streams they survey or pass survey results to other anglers.

RECOMMENDED SNORKELING PROTOCOLS

In this section I recommend procedures for measuring fish distribution, abundance, habitat use, and size structure. The protocols outline sampling designs and procedures, illustrate the principal sources of error, and suggest approaches for reducing the error of estimates.

Timing

Seasonal timing of snorkel surveys depends on the objectives of the study and the behavior of the target species. If the objective is to estimate the abundance of fish or the habitat use by a certain life stage of a species, the investigator must have some knowledge of fish behavior. For example, if the objective is to estimate the abundance of juvenile steelhead, the survey might be conducted in summer rearing areas. If the objective is to characterize habitat used by adult bull trout before spawning, the survey might be conducted before August. Underwater counts of fish are most reliable if conducted when emigration and immigration are minimal. Resident and anadromous salmonids migrate, and their behavior and habitat use vary by season. Most species maintain relatively static summer ranges between the stabilization of streamflows in late June or July and the onset of cooler water temperatures in early September (Bjornn 1971; Edmundson and others 1968). Streams are generally suitable for summer estimates of population density between early July and late August.

Daytime underwater visibility is generally best between late morning and early afternoon when the sun is directly overhead. Cloudy or overcast days may be most suitable for sampling sites with abundant overhead cover. On clear days, dark shadows may form beneath cover, and the snorkeler must swim into the shadows to observe fish. A small halogen light may be used to search for fish in shaded locations. On overcast days, the contrast between light and shadow is reduced; fish beneath cover, such as undercut banks, can be observed farther away. If minimum depth, velocity, and temperature criteria are met, the presence of direct sunlight or the time of day may not be critical. Hillman and others (1992) found no significant relationship between the time of day and the accuracy of counts. Time of day will influence water temperature, however, and snorkelers may need to schedule surveys carefully to meet temperature criteria.

Nighttime surveys may be more effective for studying salmonids than daytime surveys under some conditions. Fish that remain concealed during daylight often move out of cover and are visible at night (Campbell and Neuner 1985; Goetz 1990; Griffith and Smith 1993).

Ambient light levels influence the behavior and distribution of fish at night. Robinson and Barraclough (1978) observed differences in the behavior of sockeye salmon during dark moon phases compared to full moon phases. If underwater surveys are done at night, they should be completed during the same moon phase to avoid additional bias.

Minimum Criteria

Before developing the study design and selecting the appropriate sampling units, certain minimum criteria for water depth, temperature, and visibility must be met in the proposed study stream.

Depth—The area to be surveyed must be deep enough to enable observers to submerge a mask. Shallower water limits the snorkelers' ability to view fish hiding beneath and behind obstructions. Snorkelers can count fish in water that is deep enough to submerge a mask, but too shallow to float the snorkeler, provided the observer can crawl through the unit. Shallow water along stream margins makes it difficult for a team of divers to maintain an organized line while floating downstream (Schill and Griffith 1984).

Temperature—Water temperature influences fish behavior and may bias underwater counts. As temperatures decline, stream-dwelling salmonids in the Intermountain West typically migrate or seek concealment cover. Salmonids may migrate from summer habitat into other portions of the watershed as temperatures decline below 10 °C (Bjornn 1971). Movement into concealment cover at reduced water temperatures is well documented for a variety of resident and anadromous salmonids, including juvenile chinook salmon (Edmundson and others 1968; Hillman and others 1987), juvenile steelhead (Bustard and Narver 1975; Edmundson and others 1968; Everest and Chapman 1972), cutthroat trout (Bustard and Narver 1975; Griffith and Smith 1993), and rainbow trout (Campbell and Neuner 1985). The accuracy of underwater counts of juvenile salmonids declines with decreased water temperatures (Angradi and Contor 1989; Hillman and others 1992; Riehle 1990; Shepard and others 1982). At water temperatures below 9 °C, most juvenile salmonids hide during the daytime, and counts underestimate the true population. Accuracy of counts improves as temperatures increase above 9 °C (Hillman and others 1992).

The effects of temperature may be both species and stream specific. Bull trout are uncommon where water temperatures exceed 15 °C (Fraley and Shepard 1989; Goetz 1990). Lahontan cutthroat trout frequently occur in waters with temperatures up to 26 °C (Nelson and others 1992). In streams that rarely exceed 10 °C, it may be possible to accurately count fish, even at temperatures lower than 9 °C. In streams that commonly exceed 20 °C, salmonids may migrate or seek cover at temperatures warmer than 9 °C.

In general, daytime surveys of fish in summer rearing habitat should be conducted when stream temperatures exceed 9 °C. Observers should carry an accurate thermometer to measure water temperatures in each sampling unit. However, because the effects of temperature may be species and stream specific, investigators may need to adapt their survey to local temperature regimes.

Visibility—Water clarity can severely limit an observer's ability to count fish reliably. Palmer and Graybill (1986) observed a significant positive correlation between visibility and numbers of fish observed as visibility increased above 2 m. Researchers working in a variety of streams have recommended minimum visibilities ranging from 1.5 to 4 m for underwater counts (Gardiner 1984; Griffith and others 1984; Hillman and others 1992; Zubik and Fraley 1988). Researchers agree that the minimum acceptable visibility depends on the target species, the nature of the physical habitat, and the experience of the snorkeler. The water must be clear enough to allow snorkelers to see the stream bottom in the deepest sampling unit, identify fish by species, and detect fish trying to avoid the snorkeler. Within most small streams of the Intermountain West, visibility of 3 to 4 m will meet the listed criteria. Larger, deeper streams will require greater water clarity. In most cases, abundance estimates should not be made in units where water clarity does not exceed maximum water depth. As visibility increases, fewer snorkelers are needed to survey an entire unit.

The parent geology of a watershed can provide clues about the potential clarity of its waters and the suitability of snorkeling for sampling salmonid populations. Most streams draining granitic rock have low suspended sediments, are unproductive (have low dissolved solids), and have high visibility. In contrast, streams draining sedimentary or volcanic rock often have high levels of suspended sediment, are very productive, and have low visibility.

Observers should periodically measure the visibility of a known object in stream reaches to be surveyed. Do not assume underwater visibility is adequate without measuring it. A suitable object for measuring visibility is a silhouette of a salmonid drawn with parr marks and spots. Estimate visibility by averaging measurements of the minimum distance at which the marks on a silhouette are visible to the snorkeler. To locate the minimum distance, the snorkeler moves away from the object and notes the distance at which it disappears, then moves toward the object and notes the minimum distance at which it reappears clearly. Storms and other events can periodically reduce visibility in streams that are otherwise suitable for snorkeling. If this occurs, stop snorkeling and resume after conditions improve.

In some portions of some sampling units, turbulence will reduce local visibility, even though water clarity in the unit is adequate. Snorkelers should survey areas surrounding the turbulence first and then attempt to survey the turbulent areas. Salmonids typically maintain territories outside areas of extreme turbulence although they may seek cover in turbulent areas if disturbed.

Selecting Appropriate Sampling Units

The selection of sampling units is controlled by the objectives and design of the study, physical characteristics of the stream environment, and the investigator's budget. Good experimental design is crucial to distinguish among different hypotheses (Hurlbert 1984). Design of experiments is beyond the scope of this guide. The reader is urged to review texts on the subject and papers by Hurlbert (1984), McAllister and Peterman (1992), and Romesburg (1981).

Underwater survey techniques are flexible; sampling units can be adapted to the investigators' needs. A variety of sampling units may be selected.

One investigator may select sample units that include several habitat types (pools, runs, riffles, glides) and that represent large segments of the stream. Schill and Griffith (1984) estimated the seasonal abundance of Yellowstone cutthroat trout in the Yellowstone River. They selected four sampling units ranging from 350 to 1,316 m long, composed of several habitat types.

Another investigator may stratify a large watershed into sections and sample units within each section. Thurow (1985) monitored the abundance of juvenile steelhead in a 160-km section of the Middle Fork Salmon River. He systematically selected 20 sampling units spaced about 8 km apart. To maximize the number of fish counted, he selected units in optimal steelhead rearing areas consisting of pocket-water habitat.

Other investigators may stratify small streams into habitat units, count fish in a random or systematic sample of the units, and extrapolate abundance estimates from the sampled units to a total estimate for each stream. Hankin and Reeves (1988) estimated the total abundance of fish in small coastal streams. The authors estimated the total area of each habitat type. After the starting point was randomly selected, sampling units consisted of systematically selected habitats of each type. Total numbers of fish were estimated in each unit and averaged. A total estimate of fish abundance in each habitat type was derived by multiplying the mean abundance per habitat type by the area of the respective habitat type and summing across all habitat types. Sampling by habitat type reduces the variance of the expanded estimate by accounting for the influence of habitat type on fish abundance.

If sampling units will be resurveyed in the future, they should be recorded permanently so other investigators can relocate them. Some useful techniques are to mark the units on a topographic map; photograph them, taking care to include permanent landmarks in the photo; and sketch a detailed map of the unit illustrating access, physical features, starting and ending points of the survey, and the point from which the photo was taken (see appendix A).

Snorkeling Procedures

When selecting an appropriate snorkeling procedure, the investigator must consider the direction of the survey, the number of snorkelers required, and the type of estimate desired.

Where feasible, moving upstream against the current is the most effective snorkeling technique. Snorkelers should enter the water downstream from the unit to be surveyed and proceed upstream slowly while avoiding sudden movements (fig. 1). Because most salmonids face the current, a snorkeler moving upstream is less likely to startle fish. As Heggenes and others (1990) reported, a snorkeler who moves slowly can nearly touch fish before they are frightened. Fish are counted as the snorkeler passes them so duplicate counts are avoided. Any fish that reenter the observer's view can be seen moving upstream. When it is impractical to move upstream, snorkelers may enter the water upstream from the sampling unit and float downstream with the current, remaining as motionless as possible. Fish are counted by species and size class. Sizes can be estimated by approaching fish, aligning their snout and tail with adjacent objects, and measuring that distance with a rule or marked glove (see Training, Estimating Fish Size).

Water clarity, physical obstructions, and the type of estimate will determine the number of observers needed to complete the survey. As a general rule, enough snorkelers are needed to complete the survey in a single pass. The following section describes various types of estimates and considerations for the number of observers required.

Direct Enumeration—Direct enumeration procedures can be used to count the total number of fish within a given sampling unit. Typically, either one observer or multiple observers count all fish in a single pass. This method assumes the counts of fish are accurate.

In small streams with excellent visibility, one snorkeler may be able to see from bank to bank. The observer counts all fish in the entire sampling unit using one of three approaches. Depending on the characteristics of the unit, the snorkeler can proceed up the center of the unit and count fish by zigzagging outward

Figure 1—In small streams, one snorkeler enters the water downstream from the sampling unit and proceeds slowly upstream.

to both banks (fig. 2). Care should be taken to search for fish throughout the unit, including the margins, and to inspect all cover components (such as undercut banks, substrate, organic debris). If the water is too deep or turbulent to zigzag and visibility is adequate, the observer moves up one bank of the unit and counts all fish to the other bank. In water too deep to count upstream, the observer floats down the center of the unit and counts all fish from bank to bank, remaining as motionless as possible.

Although water clarity may allow one observer to see across the width of the channel, another snorkeler may be needed to count fish concealed by visual obstructions such as boulders, ledges, and organic debris if all fish are to be counted in a single pass. Shallow habitats (pocket water, riffles) typically require more observers than deep-water habitats. To avoid recounting fish, observers should stay adjacent to each other, move at the same speed, and only count fish that pass them.

If two snorkelers are used, the unit is divided, and snorkelers use one of three techniques. Where feasible, the unit is divided in half. Snorkelers begin in the center of the unit, move upstream shoulder to shoulder, and count all fish between themselves and the bank (fig. 3). If the unit is too deep or turbulent to allow that approach, snorkelers can use natural breaks and features such as boulders to divide the unit. Snorkelers count all fish in their portion of the unit. In water too deep to move upstream, two snorkelers lock hands and float down the center of the unit, counting all fish from their shoulders to the bank.

With three or more snorkelers, the unit is divided into equal corridors. Snorkelers proceed upstream and count all fish in one direction between themselves and the adjacent snorkeler. Snorkelers nearest the shore also count all fish between themselves and the nearest bank. Fish are not counted until they pass snorkelers. In water too deep to proceed upstream, snorkelers hold onto lengths of PVC pipe to maintain a straight counting line (Schill and Griffith 1984) (fig. 4). The distance between observers should always be less than the maximum underwater visibility. For example, if the visibility is 6 m, snorkelers should be stationed less than 6 m apart during the survey.

When it is not feasible to count all fish from bank to bank, snorkelers may count fish within a subunit of the stream channel. Snorkelers measure the underwater visibility and count all fish within their range of vision. The area surveyed is estimated by multiplying the length snorkeled by the visible corridor.

With either one or several observers, fish are counted by species and size class. Counts are recorded on a PVC cuff or slate and later transferred to a data sheet (appendix B). After completing counts, observers or other crew members measure the surface area of the snorkeled unit. Record the total length of the unit and measure the width at three or more equally spaced intervals. The surface area can be estimated either by multiplying the length times a mean width or by calculating the area of individual segments and pooling them for a total area estimate. The density of fish is typically expressed as the number of fish

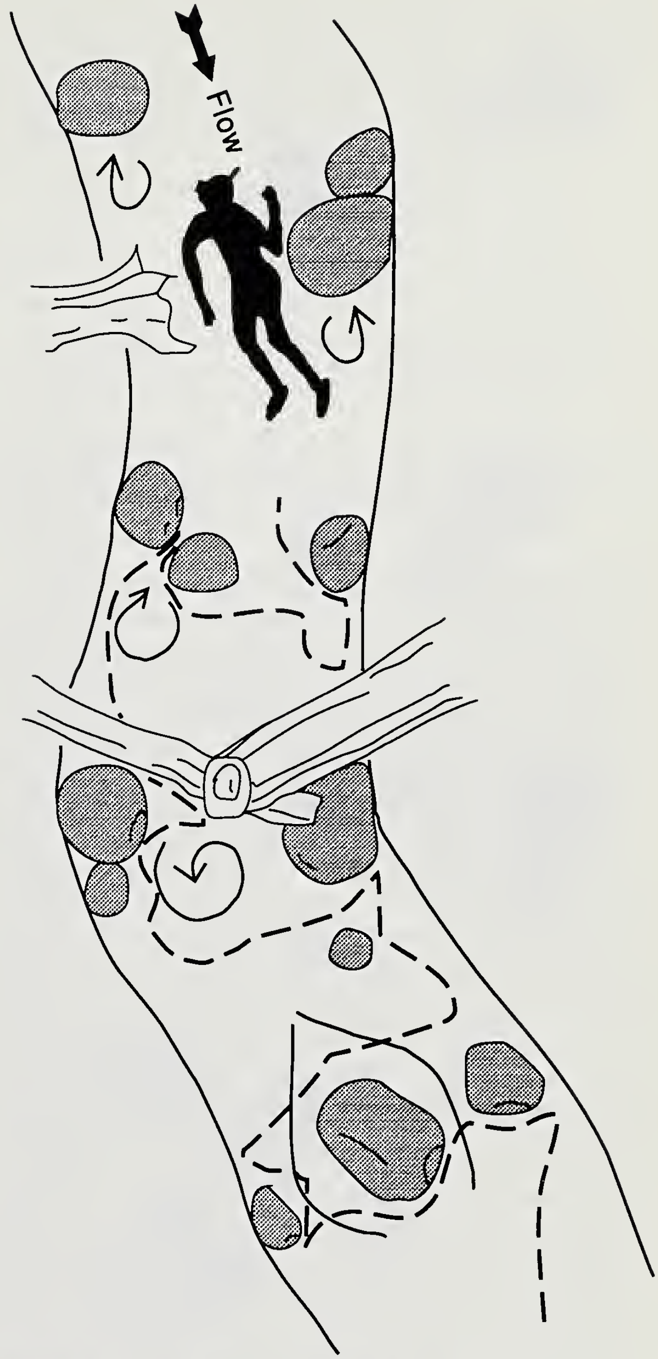

Figure 2—A snorkeler counting fish in a single pass zigzags through an entire unit while moving upstream. The dashed line represents the approximate path of the snorkeler who counts fish left and right.

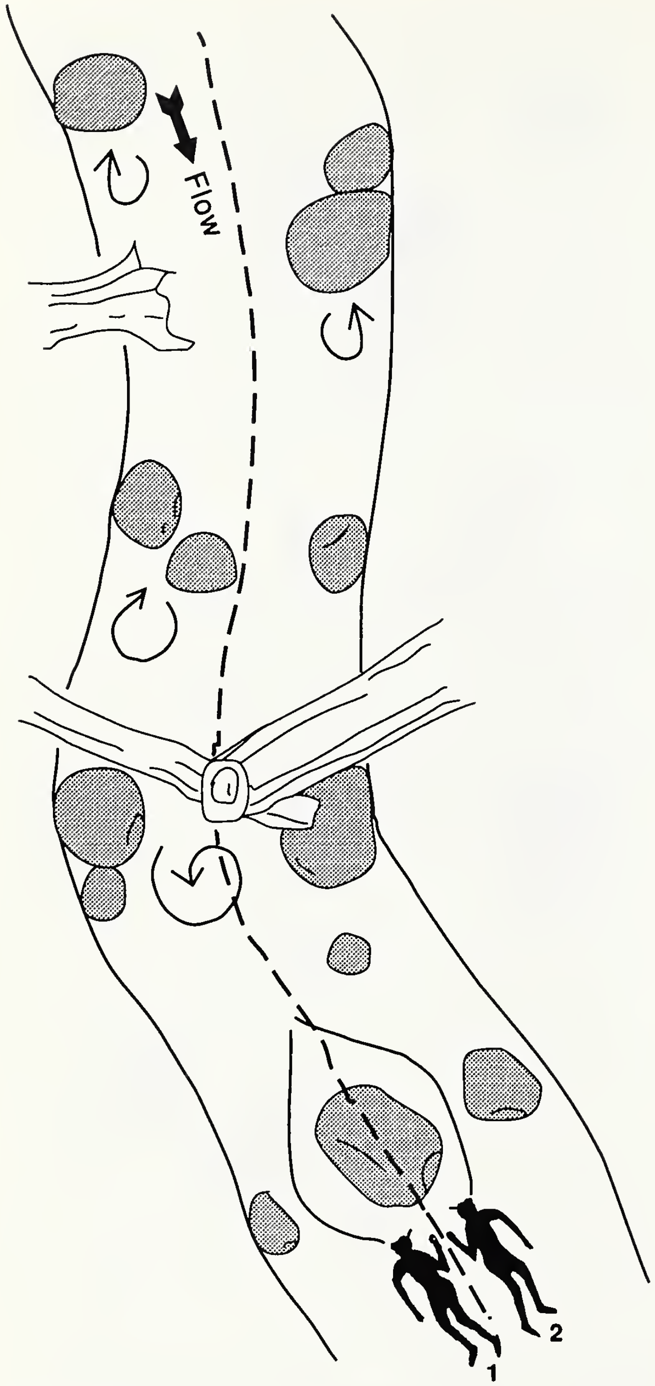

Figure 3—Two snorkelers counting fish in a unit while moving upstream. Observer 1 counts all fish to the left of center and observer 2 counts the remainder.

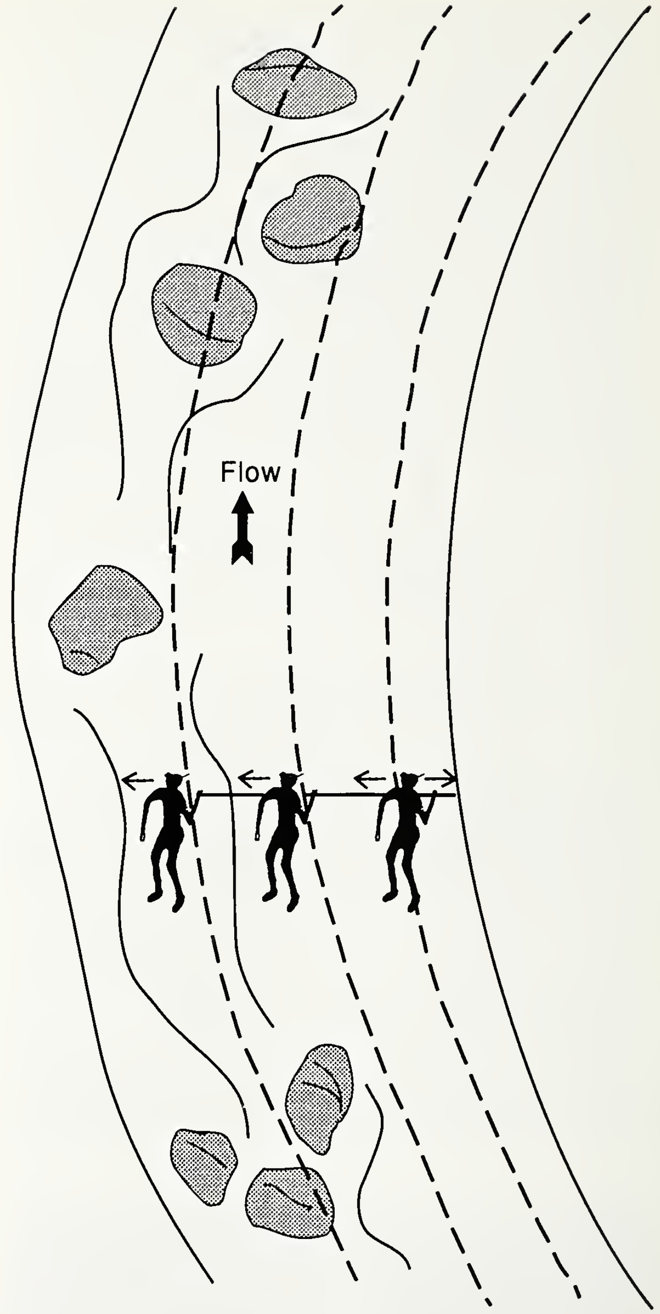

Figure 4—Several snorkelers maintaining a line with a pole as they move downstream in a large river. The unit has been equally divided, and fish are counted as the snorkelers pass them. The arrows indicate the directions each snorkeler counts fish. The dashed lines represent the approximate paths of the snorkelers.

per 100 m^2 or the number of fish per hectare. By converting fish counts to densities, the investigator standardizes the data, making it possible to compare counts spatially and temporally, both within a watershed and among watersheds.

If counts within individual units are replicated, average density and variance can be calculated, and confidence limits can be placed around the mean (Schill and Griffith 1984). Hankin and Reeves (1988) list formulas for estimating total fish abundance and calculating confidence limits around the estimates.

Expansion Estimates—The expansion method may be used to estimate the total population of fish in sampling units where total enumeration is not feasible. Expansion methods may be needed in large rivers where too few observers are available to survey the entire channel width in a single pass. This method assumes counts are accurate and the density of fish in each snorkeler's lane represents the unsampled area. The investigator typically stratifies the sampling unit into relatively homogeneous sections (such as bank and midchannel) (Grunder and Corsi 1988). Within each stratified area, counting lanes are selected randomly with widths less than or equal to the underwater visibility. One snorkeler counts the number of fish within each counting lane. Several snorkelers can count adjacent lanes simultaneously (see Snorkeling Procedures, Direct Enumeration). Observers are randomly assigned counting lanes, and counts are replicated (Zubik and Fraley 1988). The total population within the unit is estimated by dividing the total number of fish counted in each homogeneous section by the percent of the section that was surveyed. For example, a total of 500 cutthroat trout are counted in lanes representing 60 percent of the sampling unit. Five hundred is divided by 0.6 to derive a total population estimate of 833 cutthroat trout. If the unit encompassed 1.5 ha, the population density equals 556 fish per hectare. If counts within individual lanes are replicated, the mean density, variance, and confidence limits can be calculated (Slaney and Martin 1987).

Mark-Recapture Estimates—Underwater observation can also be used in concert with other techniques to derive mark-recapture population estimates. Researchers have captured fish with angling gear and marked them with brightly colored tags that are visible underwater (Slaney and Martin 1987; Vore 1993; Zubik and Fraley 1988). Colored tags can be used to differentially mark each size class of fish. After the marked fish redistribute in the sampling unit, a snorkeler or team of snorkelers record the number of marked and unmarked fish by species and size class. This method assumes no immigration or emigration occurs from the time of marking until the recovery survey, marking does not affect mortality, and both marked and unmarked fish are randomly mixed and have equal chances of being seen. When sample sizes are sufficient, population estimates are calculated for each size class using Chapman's modification of the Peterson mark-recapture technique (Ricker 1975):

$$\frac{(M+1)(C+1)}{(R+1)} = N$$

where

M = number marked
C = number captured (observed)
R = number of marked fish recaptured (observed)
N = population estimate.

A total population estimate is derived by pooling the estimates for each size class. Ricker (1975) lists formulas for calculating confidence intervals around the estimate.

Habitat-Use Estimates—Direct underwater observation has become increasingly popular for observing fish in their natural environments (Heggenes and others 1990). Underwater observation is generally considered unbiased for studying fish habitat use, particularly because fish can be observed without disturbing them. Researchers have used snorkeling techniques to study habitat use of different salmonid life stages (Cunjak 1988; Cunjak and Power 1986; Fausch and White 1981; Rimmer and others 1984). Snorkelers typically move upstream through the sampling unit, searching for fish. Upon encountering a fish, the observer carefully notes the species and its focal point (the location of the fish's snout). The fish is approached and its size estimated. If more accurate estimates of fish size, weight, or food habits are required, fish can be collected underwater using several techniques. Lethal methods of capture include explosive charges (Everest 1978) and spear guns (Helfman 1983). Nonlethal capture methods include slurp guns (Morantz and others 1987), nets (Bonneau and others, in preparation), and electrofishing (James and others 1987). A weight and float can be used to mark the fish's focal point or a measurement can be taken at the focal point immediately after the fish is observed. A series of macrohabitat and microhabitat measurements can be made to describe the habitat used by the fish. This method assumes that fish are undisturbed when first sighted, so their position reflects conditions selected by the fish.

Precision and Accuracy

Precision is a measure of the repeatability of measurements. Precise estimates tend to have small variance. The statistical precision of underwater estimates of fish abundance is derived by replicating counts. Counts may be replicated temporally within the same

unit (Slaney and Martin 1987) or spatially by replicating multiple units in the same strata (Hankin and Reeves 1988). For example, observers make three counts in the same unit, calculate the mean and variance, and place confidence limits around the mean value. As another example, observers count fish in several systematically selected units of the same strata. Fish are counted in every 10th pool in a 30-km reach of stream. Two counts are completed in each of 20 pools. The means and variances of the 20 counts are calculated and used to place confidence limits around the mean value. Replicate counts require independence and may be completed by individual snorkelers or teams of snorkelers. Bias between snorkelers can be reduced by using trained observers.

When trained snorkelers are used, precise estimates of fish abundance can be obtained with underwater counts (Griffith 1981; Northcote and Wilkie 1963; Schill and Griffith 1984; Zubik and Fraley 1988). The variation between counts by experienced observers is typically small (fig. 5). Thurow and Schill (in preparation) replicated counts of age-1+ bull trout in 42 habitat units including pools, runs, riffles, and pocket water in a small (4- to 6-m-wide) stream. Mean counts ranged from one to six fish per habitat unit. Of the replicate counts, 85 percent were within one fish of the mean and 98 percent of the counts were within two fish of the mean. Hankin and Reeves (1988) replicated counts of age-1+ steelhead in 30 pools in a small (2- to 16-m-wide) stream. Mean counts ranged from 1 to 60 steelhead. Of the replicate counts, 87 percent were within 15 percent of the mean count. Regardless of the size of the stream and sampling unit, most replicate counts by trained snorkelers are precise. Biologists counted trout in eight reaches of large (22- to 38-m wide) New Zealand streams; coefficients of variation between repeated counts ranged from 2 to 11 percent (Teirney and Jowett 1990). Schill and Griffith (1984) made 28 replicate counts in 10 reaches of a large (77- to 99-m-wide) river; 93 percent of the replicate counts were within 15 percent of the average count.

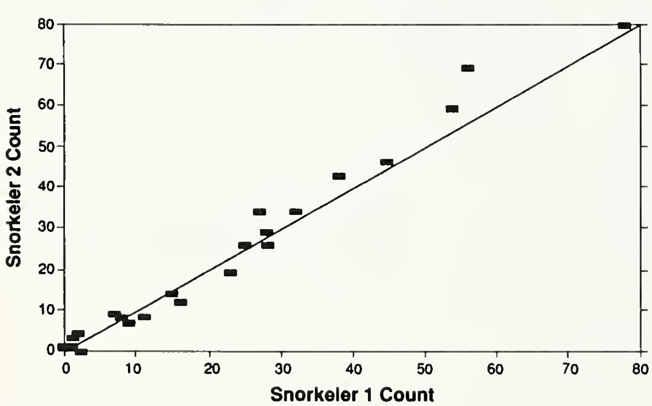

Figure 5—Comparison of independent counts of age-1+ steelhead by two snorkelers (1, 2) in 22 sampling units of the South Fork Salmon River, 1984 (Thurow 1987).

Although variation in replicate counts is typically small, the accuracy of underwater estimates has been difficult to assess because the true population density is usually unknown (Hillman and others 1992). Rodgers and others (1992) concluded that because the relative accuracy of snorkel estimates varies from stream to stream, snorkel counts should be regularly calibrated with other methods of estimating population size. The accuracy of underwater estimates has been estimated by comparing snorkel counts with abundance estimates derived from electrofishing (Griffith 1981; Hankin and Reeves 1988), seining (Goldstein 1978), and toxicants (Hillman and others 1992; Northcote and Wilkie 1963). Slaney and Martin (1987) and Zubik and Fraley (1988) reported a technique that combines snorkeling and mark-recapture estimates and can be used to calibrate snorkel counts in remote streams (see Snorkeling Procedures, Mark-Recapture Estimates).

Of 13 studies I reviewed in which population estimates were compared with snorkeling estimates of fish abundance, the snorkeling estimates were within 70 percent of the actual population estimates in all but two cases (table 1). Snorkelers observed from 75 to 78 percent of the bull trout estimated by electrofishing. Snorkelers observed from 74 to 105 percent of the cutthroat trout estimated by electrofishing and mark-recapture estimates based on snorkeling. Estimates larger than 100 percent suggest that either the comparison method underestimated the actual population size, or snorkelers counted some fish more than once. Snorkelers observed 96 percent of the steelhead and 102 percent of the brook trout estimated by electrofishing. Hillman and others (1992) observed an average of 22 percent of the age-1+ steelhead collected with sodium cyanide. One factor that may have contributed to the inaccuracy of Hillman and others' (1992) underwater estimates was that fish concealed themselves in the substrate, even at water temperatures warmer than 10 °C.

Investigators do not have enough information to calibrate snorkeling estimates with more accurate estimates of fish abundance for all species and life stages under all habitat conditions. In the absence of more complete information, investigators can standardize snorkeling procedures in an attempt to increase precision and periodically compare their fish abundance estimates with estimates derived from other methods.

Table 1—Comparisons of salmonid population estimates made by daytime snorkeling and other techniques at water temperatures warmer than 10 °C

Species	Size class	Stream size, width, flow	Percent of actual population observed by snorkeling: Mean	Standard deviation	(Range)	*N*	Means of estimating actual population	Source
	mm		*Percent*					
Brook trout	>100	Small, 4-6 m wide, 0.06-0.10 m^3/s	101.7	0.8	(101 - 103)	3	Electrofishing	Griffith 1981
	>75	Small, 5 m wide	110.0	—	—	1	Electrofishing	Hillman and Chapman 1993
Brown trout	>75	Small-medium, 9-18 m wide	105.8	12.9	(94 - 126)	5	Electrofishing	Hillman and Chapman 1993
Bull trout	>75	Small, 3-10 m wide	78.3	35.6	(47 - 117)	3	Electrofishing	Shepard and Graham 1983
	>100	Small, 4-6 m wide 0.71 m^3/s	74.9	15.3	(48 - 86)	14	Electrofishing	Thurow and Schill, in preparation
Cutthroat trout	>75	Small, 3-10 m wide	94.8	17.1	(71 - 117)	5	Electrofishing	Shepard and Graham 1983
	>200	Large, 40+ m wide 19-22 m^3/s	74.1	17.3	(51 - 92)	4	Mark-recapture by angling and snorkeling	Slaney and Martin 1987
	110-430	Large, 30-45 m wide 12-14 m^3/s	105.4	3.8	(102 - 110)	3	Mark-recapture by angling and snorkeling	Zubik and Fraley 1988
	>75	Small, 4-6 m wide 0.06-0.10 m^3/s	102.4	2.8	(100 - 104)	4	Electrofishing	Griffith 1981
Rainbow trout	>100	Large, 14 m^3/s	59.0	—	(36 - 86)	12	Rotenone	Northcote and Wilkie 1963
	>75	Small, 5-9 m wide	90.8	19.7	(77 - 105)	2	Electrofishing	Hillman and Chapman 1993
Steelhead	>100	Small, 2-16 m wide 0.8 m^3/s	96.3	44.8	(50 - 209)	14	Electrofishing	Hankin and Reeves 1988
	>100	Small-medium	21.8	25.4	(0 - 42)	15	Mark-recapture with sodium cyanide	Hillman and others 1992

SPECIES IDENTIFICATION AND HABITATS

As discussed earlier (see Training), snorkelers must practice before conducting surveys if they are to identify species accurately. The following descriptions are intended to help snorkelers identify species by observing size, coloration, morphology, and behavior. Appendix C illustrates the external characteristics of a typical salmonid. Appendix D illustrates the diagnostic external features of eight species of juvenile salmonids.

The sizes of salmonids surveyed will depend on the objectives of the study and the reliability with which different size and age groups can be identified. Summer estimates of salmonid abundance should be limited to age-1+ fish for all species except chinook salmon. Young-of-the-year (YOY) chinook salmon typically emerge in April or May. By early summer, YOY chinook salmon are large enough for snorkelers to identify accurately. In contrast, summer counts of YOY brook (*Salvelinus fontinalis*), bull, and cutthroat trout and steelhead are typically unreliable. Young-of-the-year fish of these four species are similar in size and color in summer; they may be indistinguishable to all but the most experienced snorkelers. Most will be smaller than 80 mm during surveys in July and perhaps as late as August. Small fish typically occupy the shallow stream margins where snorkeling is less effective. Griffith (1981) counted only 20 percent of the YOY brook trout estimated by electrofishing, compared to 102 percent of the age-1+ brook trout. Timing of emergence varies depending on water temperatures, and YOY fish may be present during surveys one year and not the next. In 1984, YOY steelhead in a reach of the South Fork Salmon River began emerging on July 14; 98 percent of the fry emerged by August 10 from redds that were capped with a net (Thurow 1987). In 1985, lower stream discharge and warmer water temperatures accelerated emergence; steelhead fry began emerging from redds on July 3; 98 percent of the fry had emerged by July 17 from capped redds. Although abundance estimates of YOY fish may be unreliable, observers should record the presence of YOY salmonids to indicate that adults may have spawned in the vicinity of the sampled unit.

In order to assess size and age groups of fish accurately, the observer must understand the structure of the population (Griffith 1981). When information is lacking, the observer should collect a representative sample of the different size groups in the survey

area. The size groups suggested in this document are intended as a guide. The timing of emergence and growth rates vary among watersheds, and observers need to adjust their size classes accordingly. This is particularly true for estimating age classes of steelhead and other trout.

Anadromous Salmonids

Historically, anadromous salmonids in the Intermountain West were widely distributed in tributaries to the Snake River in Idaho. Current populations are confined to the Snake River basin downstream from Hells Canyon Dam, including the Clearwater and Salmon River drainages. Species include steelhead, three races of chinook salmon (spring, summer, and fall), and sockeye salmon. Snake River coho salmon (*O. kisutch*) are extinct.

The abundance of wild anadromous stocks has declined severely and, as described earlier (see Considerations Before the Survey, Ethics), all stocks of salmon are protected under Section 7 of the Endangered Species Act. Wild steelhead are listed as a sensitive species, and adults are protected from angler harvest. Hatchery-reared anadromous fish have been widely introduced in attempts to supplement declining wild stocks.

Investigators should evaluate the stocking history of the drainage to be surveyed. If hatchery-reared fish have been introduced, it may be desirable to distinguish wild from hatchery fish during the survey. The adipose fin has been removed from all hatchery-reared steelhead and some chinook salmon parr or smolts, and a ventral fin has been removed from all chinook salmon parr or smolts stocked in Idaho waters (Kiefer 1993). Hatchery-reared parr or smolts may also be larger than wild fish of similar age. Fish stocked as fry may not be distinguishable from wild fish.

Steelhead—Juvenile steelhead use most areas of a watershed; they typically represent the most abundant salmonid in Intermountain streams that are accessible to anadromous fish. Three distinct size classes are usually present: age 1 (70 to 130 mm), age 2 (130 to 200 mm), and age 3 (200 to 250 mm) (Everest 1969; Thurow 1985). Age classes may vary among drainages. Steelhead color varies; fish are typically bluish to olive green on the back. Their sides are a lighter color, silver with a faint horizontal reddish band and oval parr marks (fig. 6). The ventral surface is white or silver. Steelhead have irregular black spots on the back, sides, head, and dorsal and caudal fins. Pelvic and anal fins have a distinct white tip. The anal fin is taller than it is long. The maxillary of juvenile fish is short and does not usually extend past the posterior margin of the eye.

Steelhead usually maintain daytime stations closely associated with submerged cover. They tend to prefer rubble-boulder substrates and fast water. Steelhead are territorial; they maintain some space between themselves and other fish.

Chinook Salmon—Formerly abundant, chinook salmon populations have declined rapidly since the 1960's; wild stocks in several tributaries are approaching extinction. Juvenile chinook will be of two discrete size classes: age 0 (50 to 80 mm) and age 1 (longer than 100 mm).

Young salmon are typically greenish blue to black on the back. Their lower sides are silver, and the ventral surface is white (fig. 7). The back, top of head, and upper sides are spotted. The dorsal fin is not spotted, and the adipose fin is partially pigmented. The caudal fin is distinctly forked, and the eyes are large, relative to the head, compared to other species described here. Parr marks are large, broad, vertical bars centered on the lateral line. The anal fin is longer than it is tall.

While juvenile chinook salmon tend to occupy C-type channels (low-gradient, low-velocity, meadow reaches) (Rosgen 1985), they may use a variety of habitats. They usually associate with organic debris and overhead cover. Juvenile fish generally feed in groups in the water column, in side channels, or along stream margins. Adult chinook typically stage in large pools (deeper than 1 m) when returning to natal spawning areas.

Sockeye Salmon/Kokanee—Within the Intermountain West, sockeye salmon and their resident form, kokanee, were indigenous to tributaries of the Salmon and Payette River drainages in Idaho. Remnant populations of sockeye salmon remain in waters of the Salmon River drainage. Kokanee remain in their historic range and have been introduced widely throughout the Intermountain West.

Kokanee and sockeye salmon differ little in coloration. The dorsal surface of the head and back is steel blue to green blue with few spots. Sides are silver with the ventral surface white to silver. Breeding males have red-gray to bright red sides and olive-to-green heads (fig. 8). Breeding females have red-gray sides and olive heads. The body is elongated, streamlined, and compressed laterally. The head is conical, and the snout and mouth are large. The dorsal fin is not spotted, and the adipose fin is not pigmented. The caudal fin is distinctly forked. Parr marks on juvenile fish are narrow, vertical bars that do not extend below the lateral line. Sockeye salmon/kokanee rear in lakes and typically school.

Figure 6—Juvenile steelhead/rainbow trout. Note the oval parr marks, prevalent spotting, and white tips on the pelvic and anal fins.

Figure 7—Juvenile chinook salmon. Note the broad, vertical parr marks, large eye, unspotted dorsal fin, forked tail, and dorsal spotting. The adipose fin has been clipped from these hatchery-reared fish.

Figure 8—Adult kokanee/sockeye salmon approaching breeding coloration. Note the elongated body, unspotted dorsal fin, forked tail, and lack of spots.

Resident Salmonids

The Intermountain West historically supported a diverse population of indigenous resident salmonids. Stream-dwelling species included rainbow or redband trout, bull trout, mountain whitefish (*Prosopium williamsoni*), grayling, and nine subspecies of cutthroat trout. A combination of factors including habitat degradation, genetic introgression, and exploitation have contributed to the decline of native salmonid populations (Rieman and McIntyre 1993; Thurow and others 1988).

Several species of resident salmonids have been propagated in hatcheries and introduced in the Intermountain West. Since the 1870's, stocks of rainbow trout have been mixed and reared in hatcheries with little regard to their ancestry (Behnke 1992). These hatchery rainbow trout stocks have been widely introduced to waters containing native salmonid populations. Similarly, cutthroat trout, especially the Yellowstone subspecies, have been introduced into Intermountain streams outside their original range (Varley and Gresswell 1988). Exotic species including brook (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) have been widely introduced.

Before conducting underwater surveys, investigators should evaluate the stocking history of target drainages to determine the species that may be present. If hatchery-reared fish have recently been introduced, it may be desirable to distinguish them from wild fish. The dorsal or pectoral fin rays will be bent or appear clipped on most fish that have been reared in hatcheries for more than 3 months.

Rainbow Trout—In drainages where steelhead are present, nonanadromous rainbow trout may be distinguished from steelhead by their size. It is unlikely that steelhead parr larger than 250 mm will migrate (Thurow 1985). It is reasonable to assume that all steelhead/rainbow larger than 250 mm are nonsmolting steelhead or resident rainbow trout. Below migration barriers, steelhead/rainbow less than 250 mm should be considered steelhead because they are indistinguishable from resident rainbow trout. Rainbow trout larger than 250 mm are usually seen in deep-water habitats. They seldom use habitats preferred by juvenile steelhead.

In drainages where steelhead are not present, resident rainbow or redband trout may be distinguished from other resident species by their coloration and parr marks. Although rainbow trout may vary in appearance among drainages, they will retain characteristics similar to steelhead (see Anadromous Salmonids, Steelhead).

Cutthroat Trout Subspecies—Cutthroat trout have the broadest distribution of any species of trout in North America (Behnke 1992). Within the Intermountain West, cutthroat trout were the most widely distributed trout in Idaho, Montana, and Nevada, and were the only native trout in Utah and Wyoming. Nine subspecies of cutthroat trout exist in the Intermountain area (appendix E): westslope, Yellowstone, Bonneville, Colorado River, finespotted, Lahontan, Paiute, Alvord (undescribed), and Humboldt (undescribed).

It is beyond the scope of this guide to describe each form. Each subspecies exhibits different coloration and spotting patterns. Snorkelers should be familiar with the distribution of cutthroat trout in their locality before conducting surveys. Behnke (1992) cites more detailed taxonomic information that can assist in identifying subspecies.

Cutthroat trout are often the most common resident trout in streams. Resident and migratory populations may be present. Fish of several age classes are usually present. It is not feasible to estimate age classes visually because age and size classes overlap. Cutthroat trout can be recorded to the nearest 100-mm length group. Most YOY fish are smaller than 70 mm.

Color and spotting pattern vary by subspecies. Most westslope cutthroat trout are greenish blue to steel gray on the back and upper sides. Their lower sides are yellow green to copper, and their belly is silver. Large fish may be distinctively red orange on the lower sides. The spotting pattern is distinct and is a good diagnostic feature: spots are irregular in shape with more spots concentrated above the lateral line and posterior to the anal fin (fig. 9). An arch drawn from the pectoral fin to the anal fin has few spots below it and several spots above it. Few spots are found on the head or anal fin.

Finespotted Snake River cutthroat trout also have a unique color and spotting pattern. This subspecies has the smallest spots of any trout native to the Intermountain West (fig. 10). The spots are profuse and resemble a heavy sprinkling of ground pepper (Behnke 1992). The color of finespotted cutthroat trout resembles that of the Yellowstone cutthroat trout. However, the finespotted subspecies has red ventral fins, and its sides may be yellower than the Yellowstone subspecies.

Juvenile cutthroat trout of several subspecies have oval parr marks and white fin margins; they appear similar to juvenile steelhead/rainbow trout. Both the spotting pattern and coloration should be used to identify cutthroat trout. The maxillary is longer than a steelhead's, extending past the posterior margin of the eye. The red/orange slash underneath the jaw may not be visible.

Cutthroat trout subspecies use all habitat types, but tend to be most abundant in pools and habitats with low water velocity. Larger fish generally use

Figure 9—Adult westslope cutthroat trout cruising through a pool. Note the distinctive spotting pattern, copper-colored sides, and orange slash underneath the jaw.

Figure 10—Adult finespotted Snake River cutthroat trout. Note the distinctive, small, pepperlike spots, reddish color of the ventral fin margins, and orange slash underneath the jaw.

deep pools and maintain stations in the water column or move through the pool. Juvenile fish associate closely with overhead and instream cover.

Bull Trout—Bull trout are the only char native to the Intermountain West and are perhaps the least understood salmonid. Resident and migratory populations exist. Fish of several age classes may be observed; some may be longer than 600 mm. Like cutthroat trout, bull trout can be recorded to the nearest 100 mm. Most YOY fish are smaller than 80 mm.

Their backs are normally olive green to brown with white or pale yellow spots (fig. 11). Their sides are pale in color with orange or red spots visible on adults and white or pale yellow spots on juveniles. Fins are tinged with yellow orange; the pectoral, pelvic, and anal fins have white borders. The dorsal fin is typically unpigmented or of a solid color. Bull trout may have vermiculations (wormlike markings) on their back, although they are not as distinctive as those of brook trout. Small fish have irregular parr marks that appear as dark blotches. Compared to other species, the head is long with a large mouth and long, blunt snout. Eyes are sloped toward the top of the head more prominently than other salmonids.

Their cryptic coloration makes bull trout difficult to see. They typically reside on or just above the substrate. Some researchers suggest that daytime counts underestimate the true abundance of bull trout and are less accurate than nighttime counts (Fraley and Shepard 1987; Goetz 1990). Schill (1991) found no significant difference in day and night counts. Bull trout appear to prefer cold water (less than 15 °C), coarse substrate, and organic debris. Because bull trout may seek cover before other species do, snorkelers

Figure 11—Adult bull trout hiding on the substrate of a pool. Note the large mouth, pale yellow spots, white fin margins, and unpigmented dorsal fin.

should scan the substrate and underwater cover immediately when entering sampling units. Snorkelers should carefully search for bull trout in potential hiding places such as debris jams, undercut banks, and crevices under boulders.

Mountain Whitefish—Mountain whitefish are abundant in many waters of the Intermountain West, and several age classes may be observed. Since most investigators do not collect information about mountain whitefish, information on their abundance, size structure, and habitat use is incomplete. Investigators are encouraged to collect such information. Age and size classes overlap; mountain whitefish can be recorded in 100-mm size groups.

Mountain whitefish are light gray blue on the back and silver on the sides, with a white belly. Their body is slender with a pointed head and small, terminal mouth (fig. 12). Scales are large relative to other salmonids and may reflect light. The adipose fin is large. Juvenile whitefish have two rows of small, round parr marks that seldom extend below the lateral line.

Whitefish use all habitat types, but they tend to be most abundant in pools and areas with low water velocity. Adults typically aggregate and forage near the substrate in deep pools.

Brook Trout—Brook trout have been introduced widely to waters in the Intermountain West. Brook trout can be recorded in 100-mm groups. Most YOY fish are less than 80 mm. Their backs are olive green to dark brown with numerous distinctive vermiculations (fig. 13). Their sides are covered with red spots encircled with blue halos. The belly is white. Anal, pelvic, and pectoral fins are black and red with a distinctive white border. The nostril has a band of dark pigment across it.

Brook trout typically live in low-gradient, C-type channels (Rosgen 1985) and pools behind beaver dams. Although they tend to be most abundant in low-velocity meadow streams, brook trout also use steeper gradient stream reaches.

Bull trout will hybridize with brook trout (Markle 1992), and the potential for hybridization exists if adults of both species are present. Hybrids may be difficult to identify. Markle (1992) suggested using the coloration of the dorsal fin as a diagnostic feature. Hybrids typically have a spotted or faintly banded dorsal fin; bull trout have an unpigmented or solid-colored dorsal fin (fig. 11); and brook trout have a banded dorsal fin (fig. 13). Adams (1994) compared visual identification of 63 fish with electrophoretic analysis of fin clips. She correctly identified 86 percent of the hybrids, 96 percent of the bull trout, and 100 percent of the brook trout. Hybrids exhibited highly variable coloration and markings; some hybrids looked like brook trout but either lacked or had only faint vermiculations, faint black or red bands on the paired fins, or faint halos around spots. Other hybrids looked like bull trout but had a spotted dorsal fin, dark bands on the paired fins, or a dark band across the nostril.

Brown Trout—Brown trout have been introduced widely in waters of the Intermountain West. Brown trout tolerate disturbances in watersheds, such as increased water temperature and turbidity, more than native salmonids.

They are olive brown on the back. Their light brown or yellowish sides have numerous brown, black, and red spots surrounded by halos of pink or gray (fig. 14). The belly is white or yellow. The adipose fin is orange.

Figure 12—Adult mountain whitefish near the bottom of a pool. Note its slender body, small terminal mouth, silver color, large scales reflecting light, and forked tail.

Figure 13—Adult brook trout. Note the vermiculations on the back, distinctive red spots encircled in halos, white borders on the fins, and banded dorsal fin.

Figure 14—Adult brown trout. Note the brown and yellow coloration and spots with gray halos.

Species Other Than Salmonids

Several species other than salmonids may be encountered during snorkel surveys. Three common species can be confused with trout or salmon: northern squawfish (*Ptychocheilus oregonensis*), redside shiners (*Richardsonius balteatus*), and suckers (*Catostomus* spp.). Although the lack of an adipose fin is a diagnostic characteristic, snorkelers should be familiar with the distribution of nonsalmonids to avoid confusion.

Northern squawfish can exceed 500 mm in length. Their body is elongate, with a long, tapered head. The snout is long, and the mouth is large. Their back is dark olive green, the sides are gray silver, and the belly is yellow white (fig. 15). The caudal fin is deeply forked. Squawfish tend to reside at lower elevations in slow-moving stream reaches. They are typically observed near the bottom of large pools.

Redside shiners generally cluster together; they rarely exceed 100 mm in length. The body is deep and compressed laterally with a long caudal peduncle and forked tail. Their back is steel blue, dark olive, or brown; the sides and belly are silver (fig. 16). Their eyes are large relative to their head, similar to chinook salmon. They can be distinguished from chinook salmon by the lack of an adipose fin and spots, and by the dark lateral stripe extending from the snout to the base of the tail. In adults, a reddish coloration is often present from the opercle to the anal fin. Redside shiners typically use slow-moving reaches of streams with warmer temperatures.

Suckers are usually observed in aggregations; they can exceed 400 mm in length. Their bodies are long, with an oval cross section. Their head is large with small eyes and a long, blunt snout (fig. 17). The mouth is ventral with thick, fleshy lips. Suckers tend to be sedentary and reside near the substrate.

Snorkelers may encounter other nonsalmonid species, including dace (*Rhinichthys* spp.) and sculpin (*Cottus* spp.). These species are typically small (less than 100 mm) and sedentary; they are not likely to be confused with age-1+ salmonids.

RESEARCH NEEDS

The accuracy and precision of underwater surveys of salmonids is strongly influenced by biological factors (behavior of the target species) and by physical conditions (environmental attributes of the sampling

Figure 15—Adult northern squawfish. Note the large mouth, forked tail, lack of spots, and absence of an adipose fin.

Figure 16—Juvenile redside shiner. Note the lack of parr marks, lack of spots, and absence of an adipose fin.

Figure 17—Sucker sp. near the substrate in a pool. Note the large head, small eye, oval cross section, and ventral mouth.

unit). Underwater surveys may be biased by the behavior of different life stages within the same species and by the behavior of various species within the same life stage. Each species and life stage may respond differently to changing environmental conditions.

Biologists do not have enough information to develop protocols for sampling the distribution and abundance of most species and life stages across the full range of existing habitat conditions. There is a need to continue comparing the accuracy of underwater surveys with other techniques. The feasibility of using underwater techniques to assess the presence or absence of fish populations that are fragmented and in low abundance has not been adequately assessed. For most species and life stages, the variability in abundance estimates across a range of habitat conditions is largely unknown. The influence of physical conditions including stream size, temperature, light intensity, cover abundance and quality, and water clarity on sampling efficiency has not been adequately described. For most species, the sampling effort required to achieve a desired level of accuracy and precision in estimating abundance is unknown.

As additional native salmonids receive protected status, underwater surveys could become more widely used as a nonlethal sampling method. Additional work on the biological and physical factors influencing underwater surveys is necessary to enable biologists to better evaluate and account for the associated bias.

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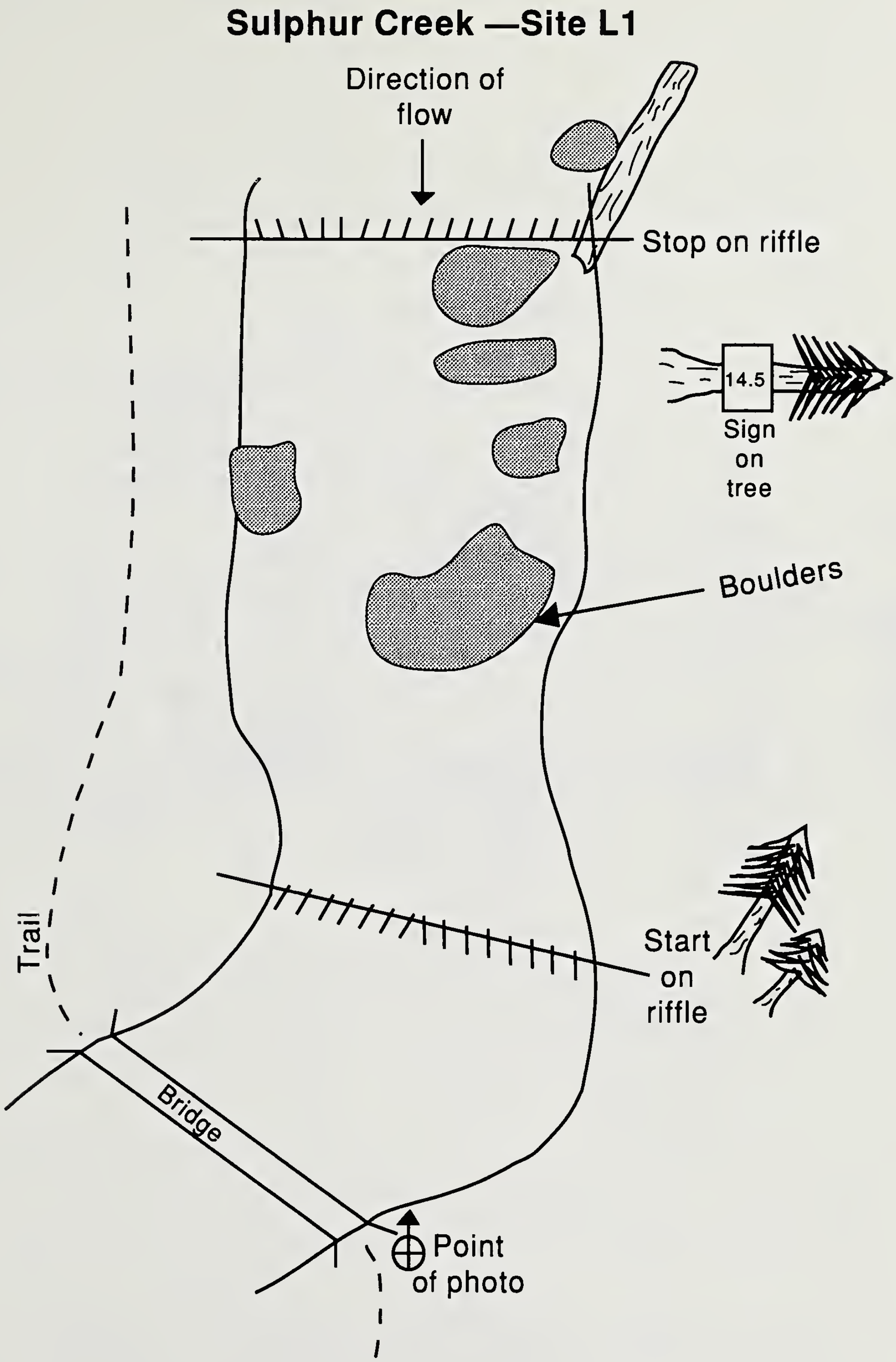
APPENDIX A: EXAMPLE OF A SAMPLING UNIT MAP



APPENDIX B: EXAMPLE OF A SNORKEL DATA SHEET

Date________________ page______ of______

Diver 1______________

Location____________________________________

Diver 2______________

Time________________ H_2O temp______________

Diver 3______________

Unit No.		Diver 1	Diver 2	Diver 3	
_____	chin 0	______	______	______	Cover:
	chin 1	______	______	______	UC______% (undercut)
	ST1+	______	______	______	OC______% (overhead)
	ST2+	______	______	______	SC______% (submerged)
	ST3+	______	______	______	LS______% (large substrate)
	RB>250	______	______	______	
	CT<100	______	______	______	
	CT 100-199	______	______	______	
	CT 200-299	______	______	______	
	CT>300	______	______	______	
	BT<100	______	______	______	Max Depth
	BT 100-199	______	______	______	(pools only)
	BT 200-299	______	______	______	________M
	BT 300-399	______	______	______	
	BT 400-499	______	______	______	
	BT>500	______	______	______	
	YOY	______	______	______	

chin = chinook salmon
ST = steelhead/rainbow
RB = rainbow trout
CT = cutthroat trout
BT = bull trout

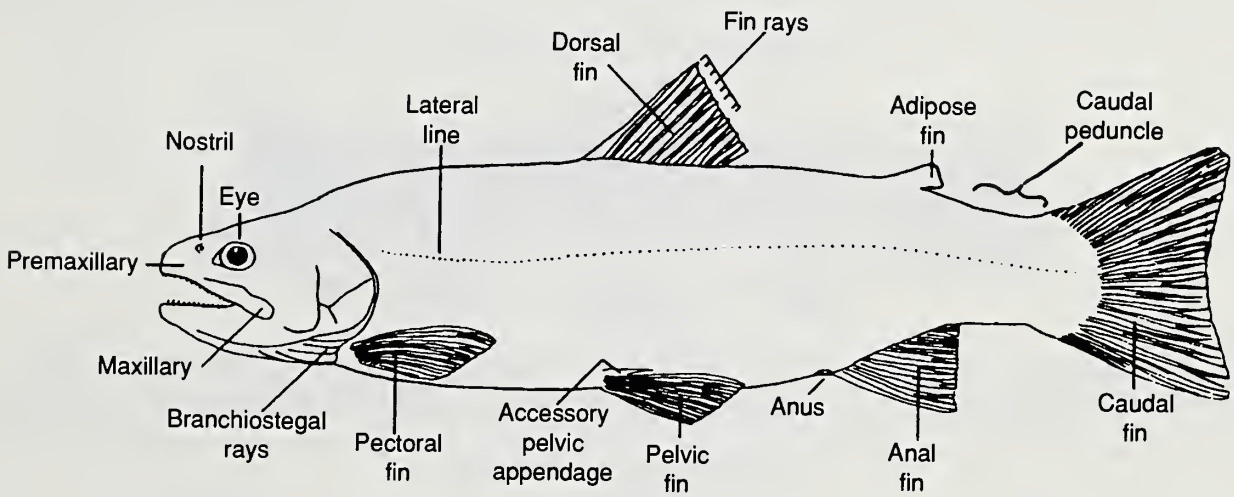
Comments:

underwater visibility

weather conditions

APPENDIX C: EXTERNAL CHARACTERISTICS OF A TYPICAL SALMONID

(Adapted from Simpson and Wallace 1978)



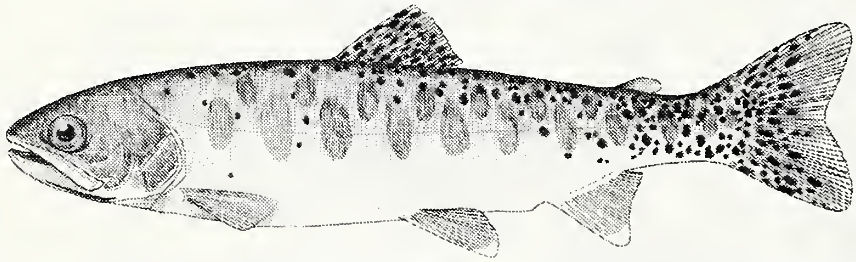
APPENDIX D: DIAGNOSTIC EXTERNAL FEATURES OF JUVENILE SALMONIDS FOUND IN THE INTERMOUNTAIN WEST

(Illustrations by Eric Stansbury, Idaho Department of Fish and Game)

Steelhead/Rainbow Trout (*O. mykiss*)

1. Abundant spots on head and body. 2. Maxillary short, does not extend past eye. 3. Dorsal fin spotted, white tip. 4. White tips on pelvic and anal fins. 5. Oval parr marks.

Cutthroat Trout (*O. clarki* subspecies)



1. Few spots on head. 2. Maxillary long, typically extends past eye. 3. Red/orange mark beneath jaw. 4. Spots concentrated near caudal peduncle. 5. White tips on pelvic and anal fins. 6. Oval parr marks.

Chinook Salmon (*O. tshawytscha*)

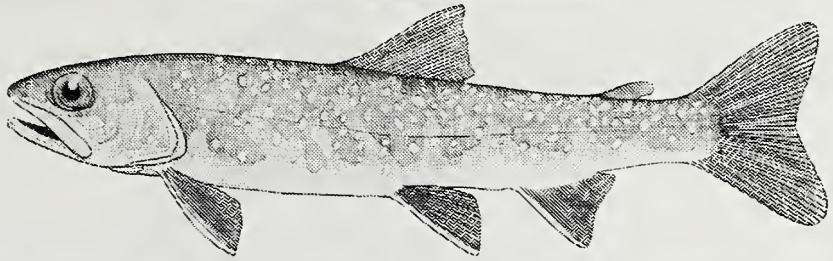
1. Large eye. 2. Abundant spots on back. 3. Broad vertical parr marks. 4. Trailing edge of adipose fin black. 5. Deeply forked tail. 6. Anal fin longer than tall.

Kokanee/Sockeye Salmon (*O. nerka*)

1. Narrow, alternating parr marks above lateral line. 2. Unpigmented dorsal and adipose fin. 3. Deeply forked tail. 4. Sides silver. 5. Anal fin longer than tall.

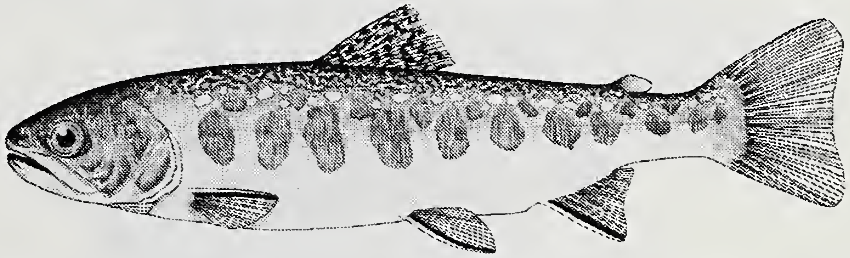
(con.)

Bull Trout (*Salvelinus confluentus*)



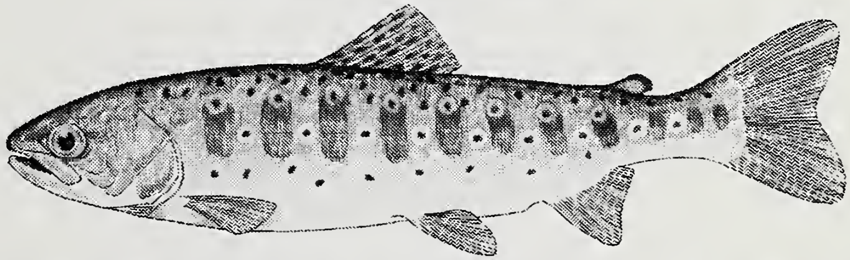
1. Large mouth and long snout. 2. Eyes sloped toward top of head. 3. White or pale yellow spots on back and sides. 4. Parr marks appear as dark blotches. 5. Unpigmented or solid colored dorsal and adipose fins. 6. White borders on ventral fins.

Brook Trout (*Salvelinus fontinalis*)



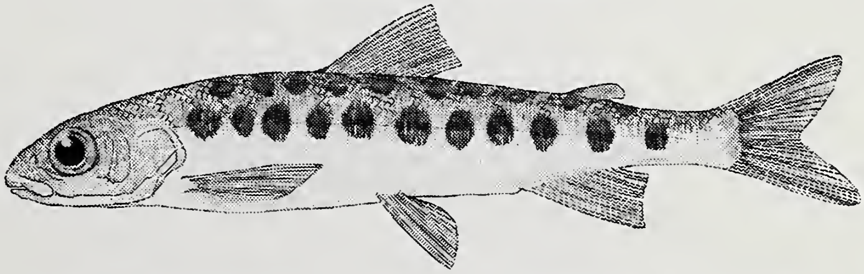
1. Dark band through nostril. 2. Vermiculations on back. 3. Banded dorsal fin. 4. Large, oval parr marks. 5. Square tail. 6. White borders followed by black and red bands on ventral fins.

Brown Trout (*Salmo trutta*)



1. Brown, black, and red spots with gray and pink halos. 2. Bar-shaped parr marks. 3. Trailing edge of adipose fin orange.

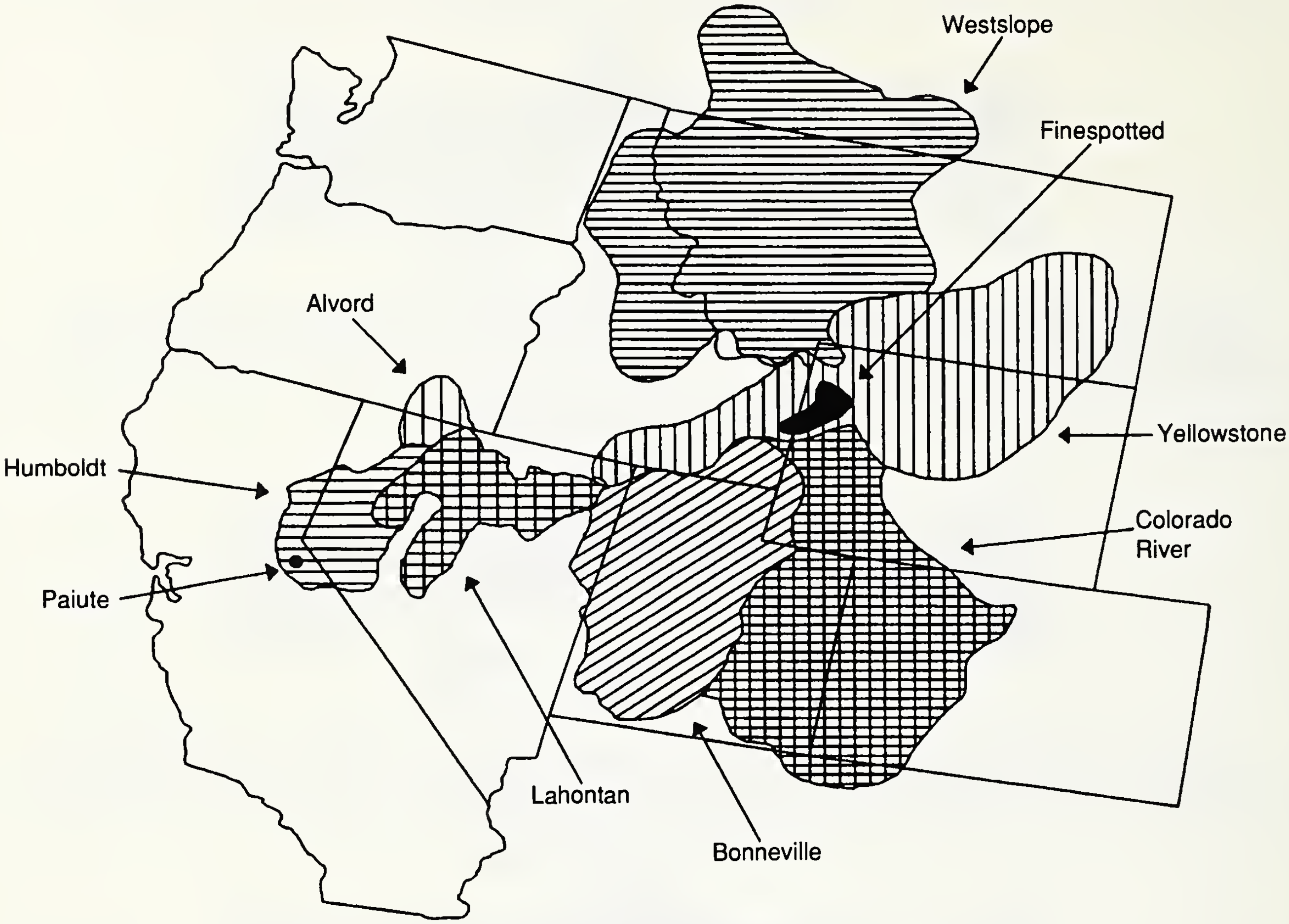
Mountain Whitefish (*Prosopium williamsoni*)



1. Pointed head. 2. Small, subterminal mouth. 3. Two rows of oval parr marks above lateral line. 4. Large, coarse, scales. 5. Deeply forked tail.

APPENDIX E: DISTRIBUTION OF INTERIOR RACES OF CUTTHROAT TROUT IN THE WESTERN UNITED STATES

(Adapted from Behnke 1992)



Thurow, Russell F. 1994. Underwater methods for study of salmonids in the Intermountain West. Gen. Tech. Rep. INT-GTR-307. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. 28 p.

This guide describes underwater methods using snorkeling gear to study fish populations in flowing waters of the Intermountain West. It outlines procedures for estimating salmonid abundance and habitat use and provides criteria for identifying and estimating the size of fish underwater.

KEYWORDS: snorkeling, underwater equipment, population estimates, habitat, Salmonidae, species identification, anadromous fishes

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

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